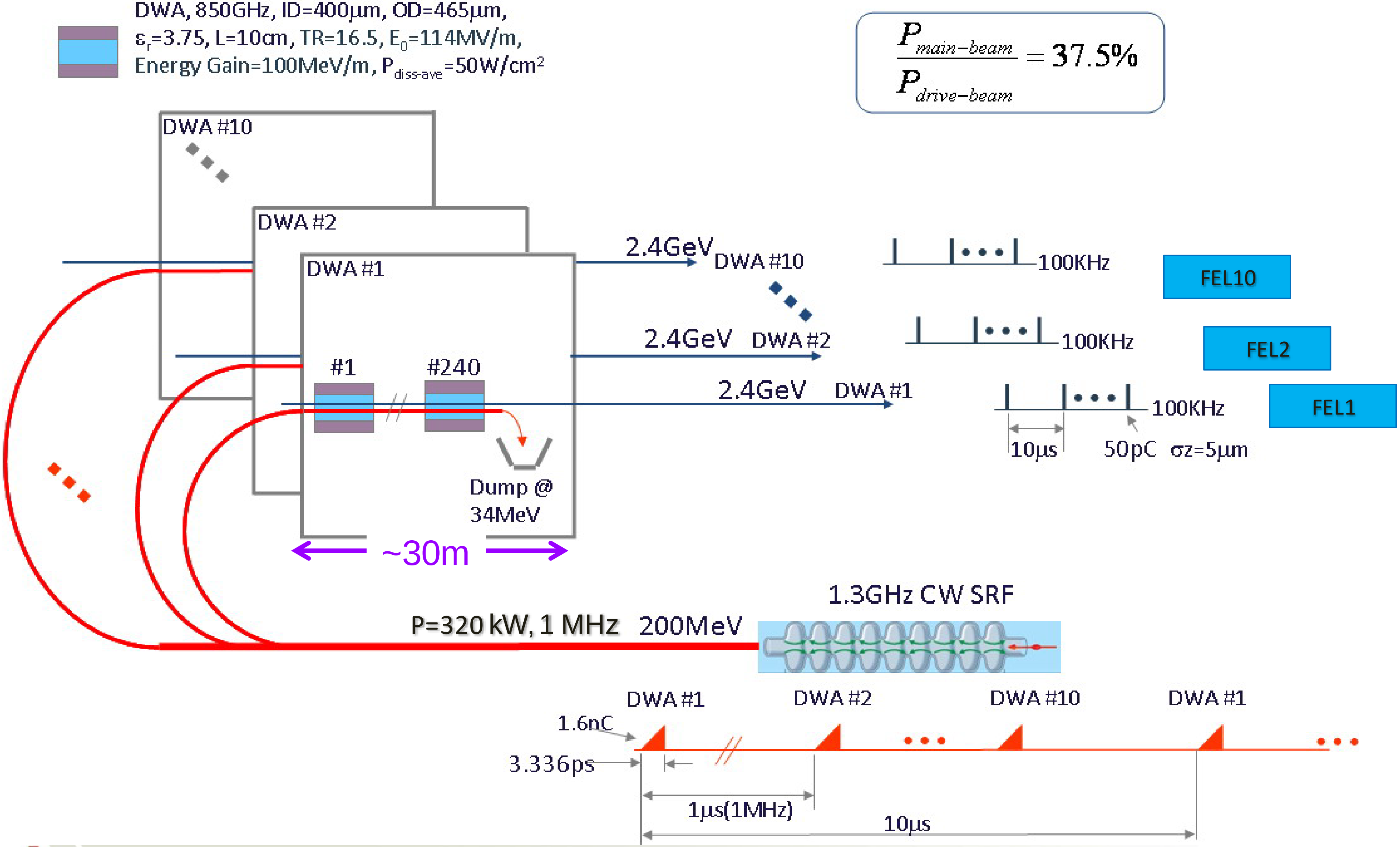
Drive beam propagation and control in a DWA channel

Chunguang Jing, Euclid Techlabs / AWA

(most of work was done by Chen Li)

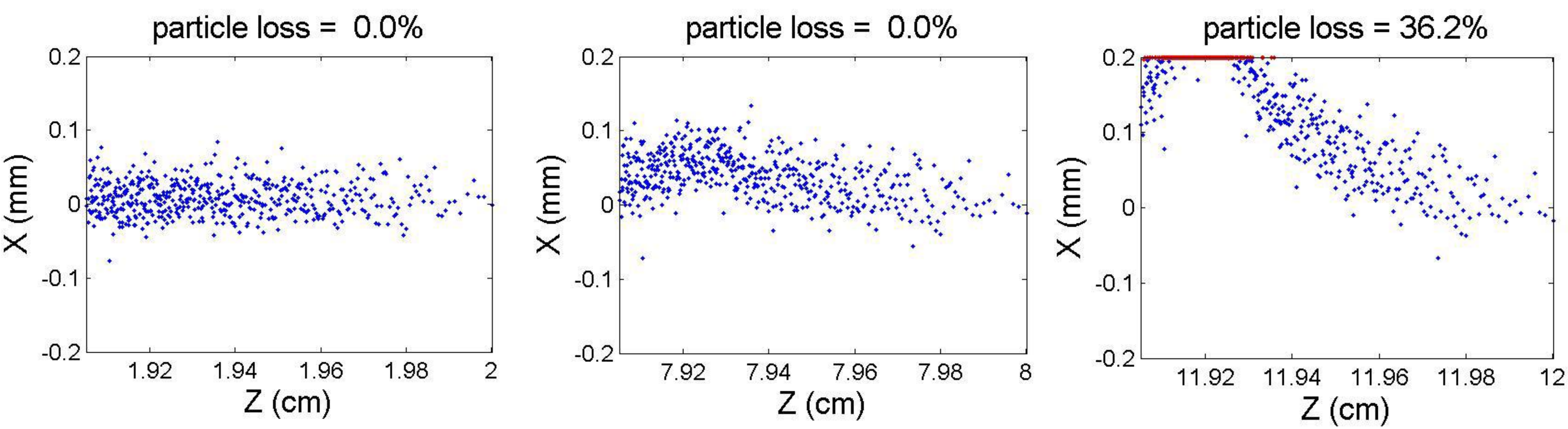
High rep. rate, X-ray FEL user facility based on a 2.4 GeV DWFA (2012)



Evolution of the DT drive bunch (no BBU control)

Initial beam parameters	Value
σx	25um
Norm. emittance	1um
Charge	1.6nC
Energy	150MeV

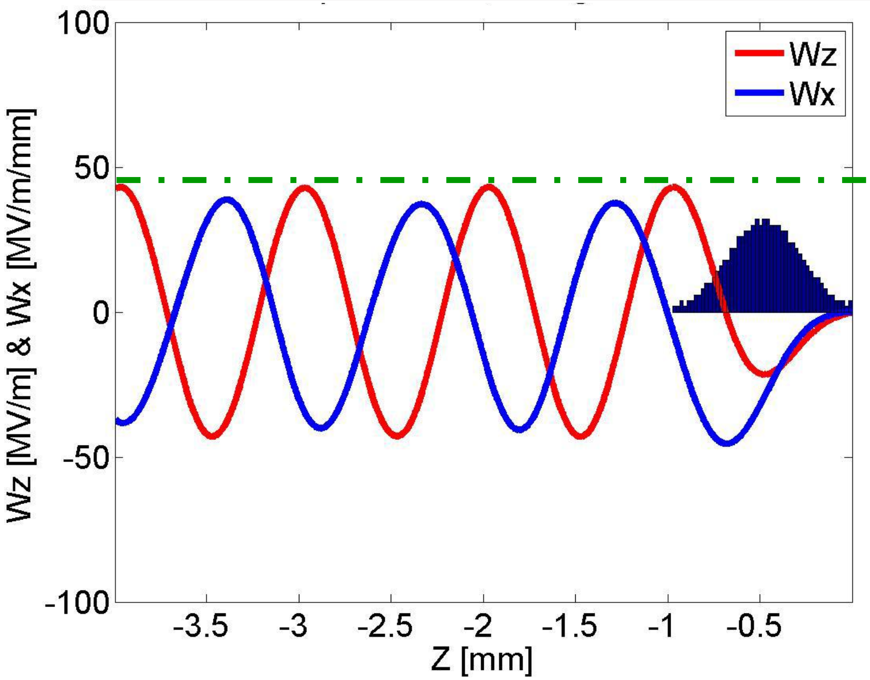
Head at 2cm from the entrance 8 cm 12 cm

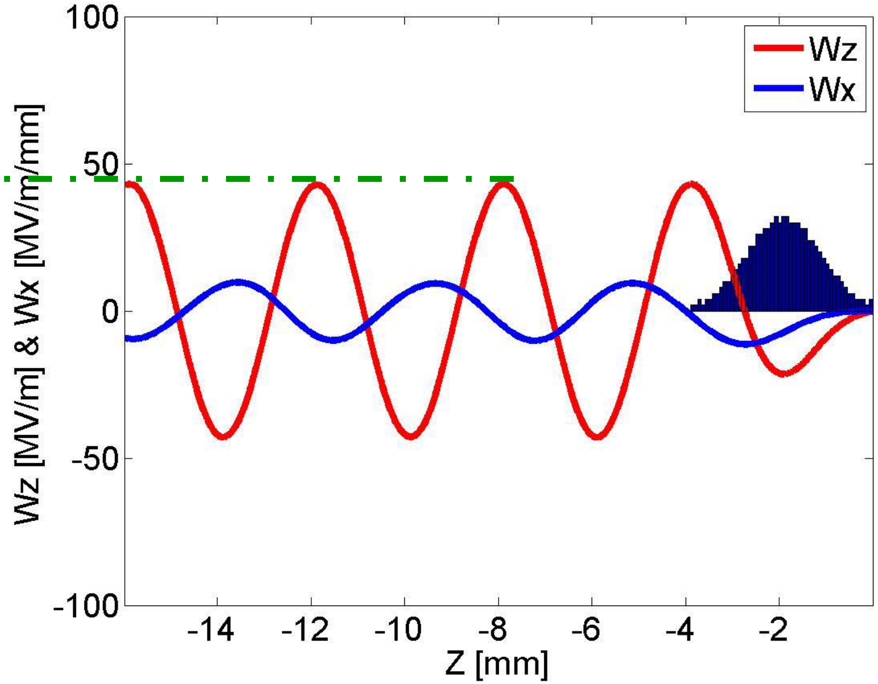


Simulation uses the same model as the paper by Wei Gai, et al, PRE 55, 3, (1997) 3481

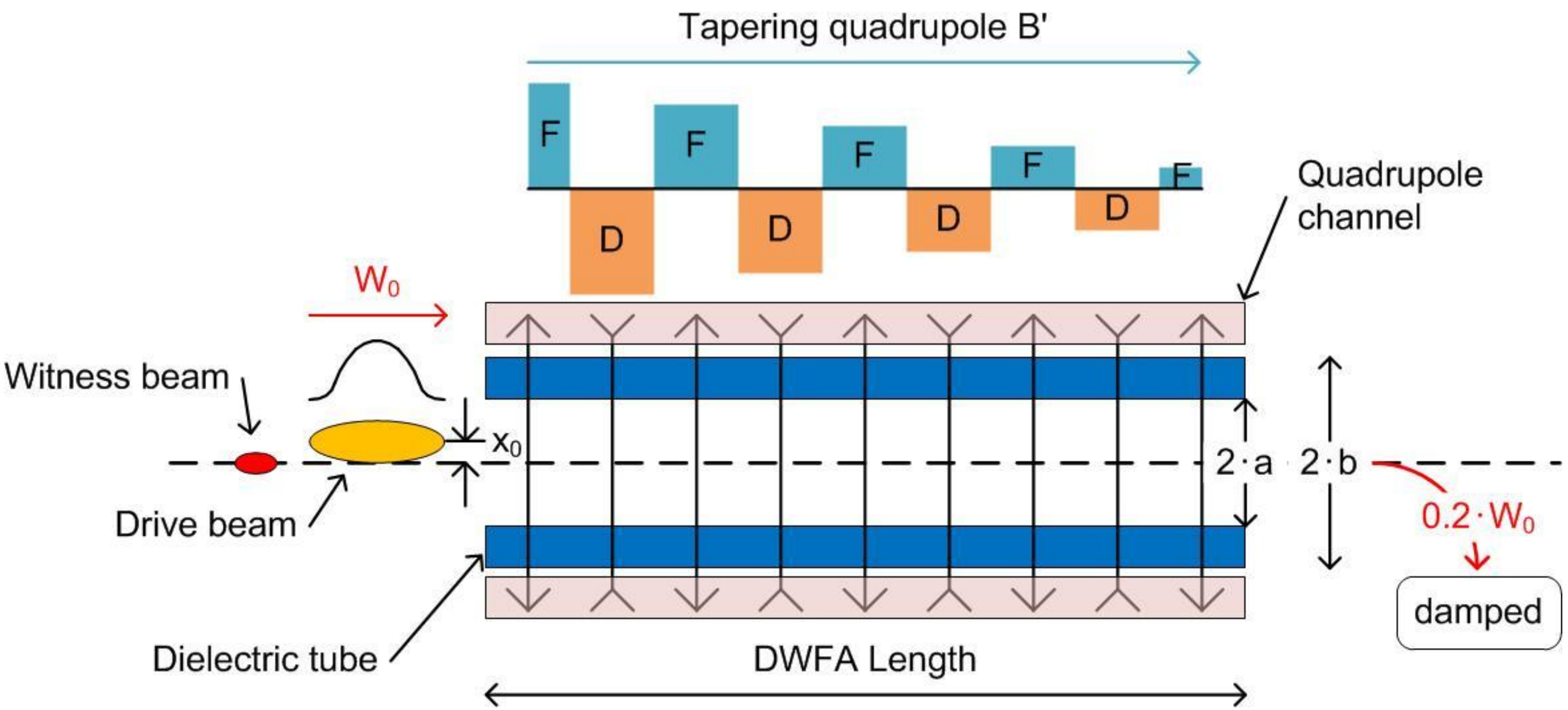
Wakefields: $W_z \sim Q/a\char`^2$, $W_x \sim Q/a\char`^3$

Case I	Case II
a=0.5mm	a=2mm
Q=1nC	Q=16nC
Freq.=300GHz	Freq.=75GHz
σz/λ=0.2	σz/λ=0.2





Ideal Quads Channel for BBU Control



Scaling law used in the simulation

parameters	scaling laws	equal to
b	$b \sim a$	$b = 1.06a$
B′ [T/m]	$B' \sim 1/a$	$B'[T/m] = 1\ [T] / a\ [m]$
k [1/m²]	$k \sim B' \sim 1/a$	$k = B'/(B\rho)$
L_q [m]	$L_q \sim \frac{1}{\sqrt{k}} \sim \sqrt{a}$	$L_q = \phi/\sqrt{k}$
W_x	$W_x \sim Q/a^3$	$W_x = W_{x0} \cdot Q[nC]/\{a[mm]\}^3$
f [GHz]	$f \sim 1/a$	$f\,[GHz] = 300 * (1\,[mm] / a\,[mm])$
rms length	$\sigma_z \sim 1/f \sim a$	$\sigma_z = 0.2\lambda = 0.2c/f$
norm emt	$\epsilon_n \sim \sqrt{Q}$	$\epsilon_n[\mu m] = \sqrt{Q[nC]}$
initial beta	$\beta_x \sim L_q \sim \sqrt{a}$	$\beta_x = \frac{L_q}{2(2+\sqrt{2})}$
initial rms size	$\sigma_x \sim \sqrt{\beta_x \epsilon_{un}} \sim (aQ)^{1/4}$	$\sigma_x = \sqrt{\beta_x \epsilon_{un}}$

Transfer matrix theory

matrix of a FOCO cell:

$$M_{FODO} = \begin{pmatrix} 1 & 0 \\ -\frac{1}{2f} & 1 \end{pmatrix} \begin{pmatrix} 1 & L_d \\ \frac{W_x L_d}{\gamma m c^2} & 1 \end{pmatrix} \begin{pmatrix} 1 & 0 \\ \frac{1}{f} & 1 \end{pmatrix} \begin{pmatrix} 1 & L_d \\ \frac{W_x L_d}{\gamma m c^2} & 1 \end{pmatrix} \begin{pmatrix} 1 & 0 \\ -\frac{1}{2f} & 1 \end{pmatrix}$$

By using some scaling laws, matrix can be written as,

$$M = M(Q, a)$$

Stability conditions requires that,

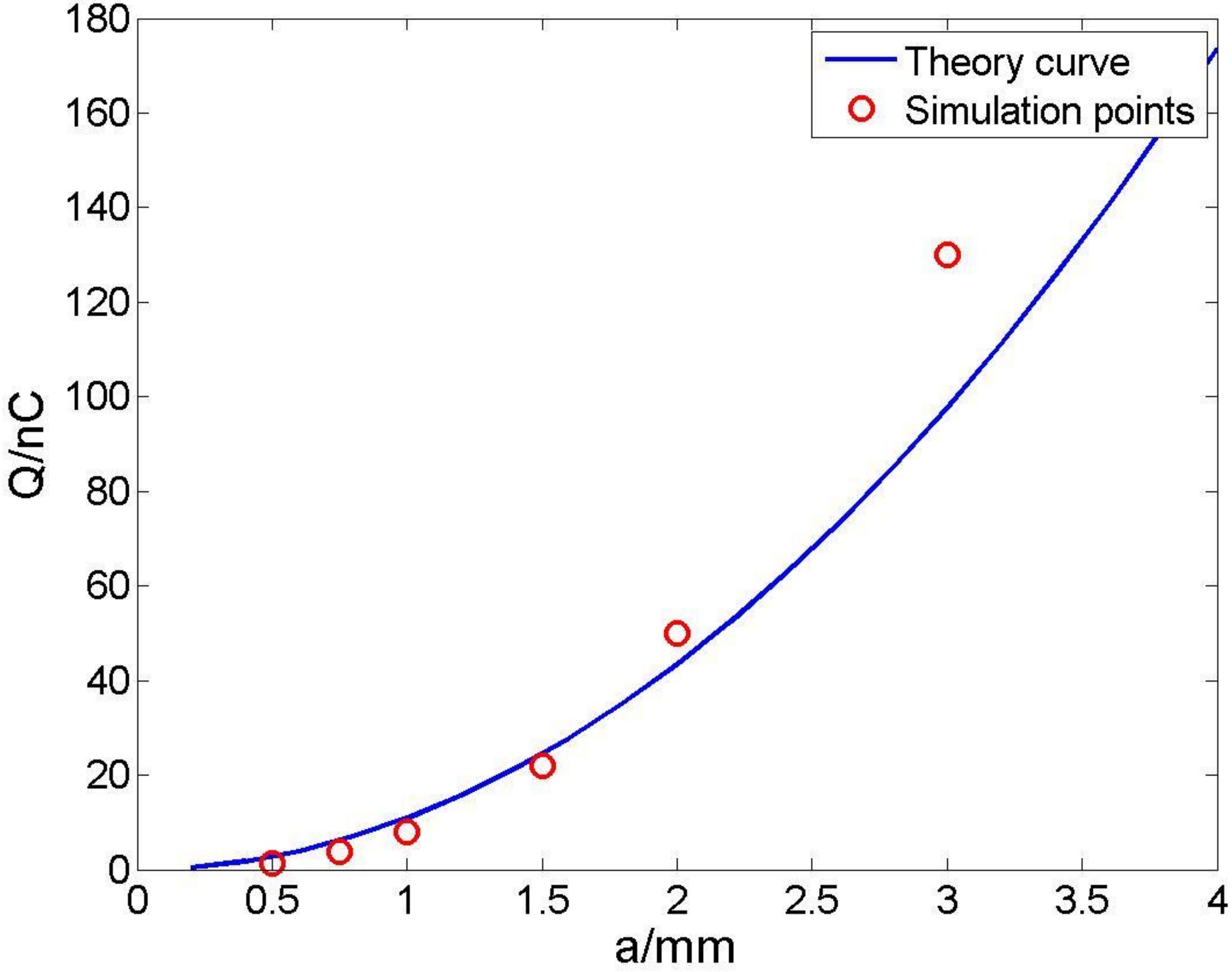
$$|Trace(M)| \leq 2$$

By applying the equal sign, boundary of Q can be solved as a function of *a*.

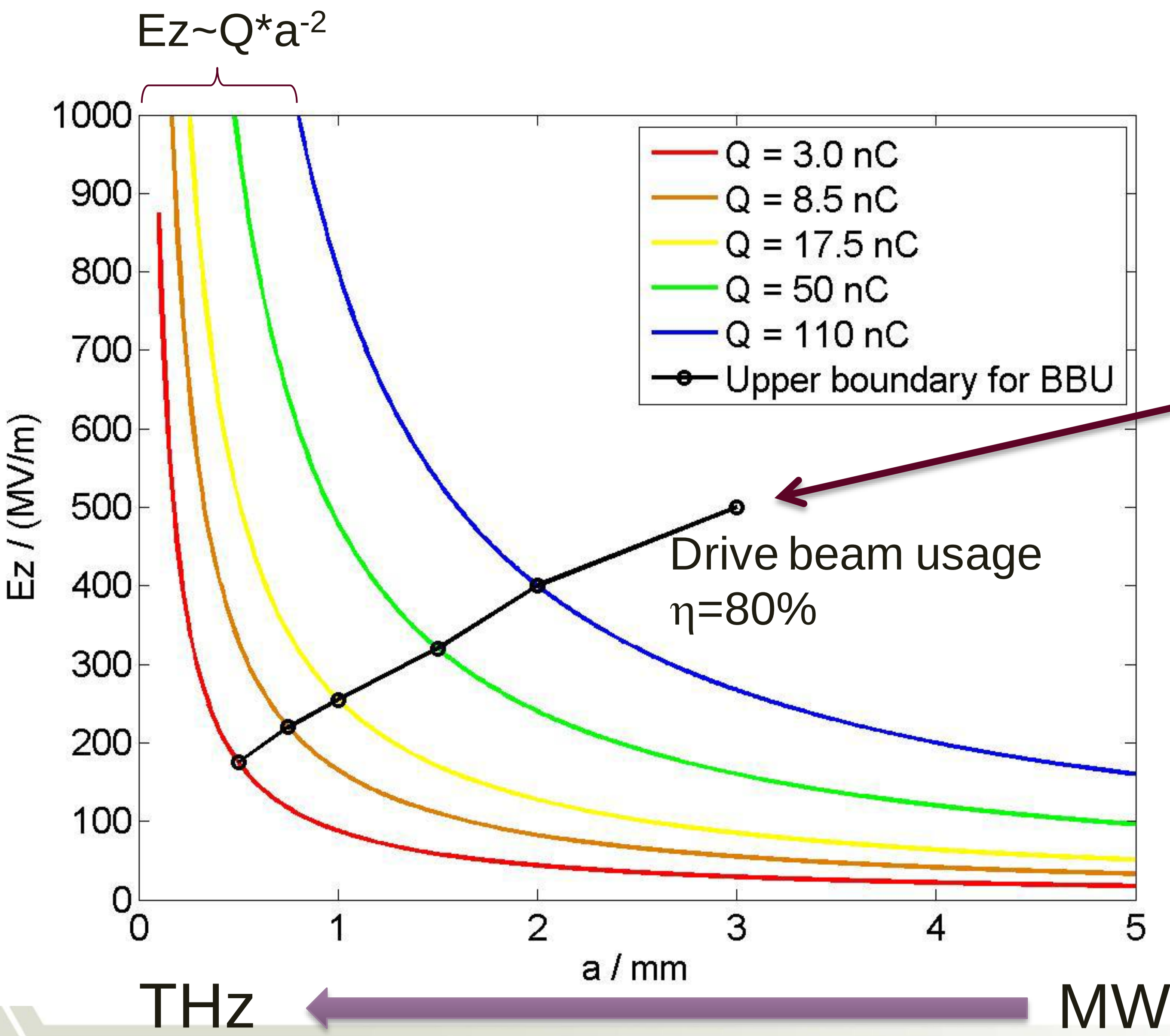
Detailed FODO parameters can be solved by the periodic condition.

How large beam charge can be controlled?

Upper boundary of beam charge *vs* beam aperture (radius)



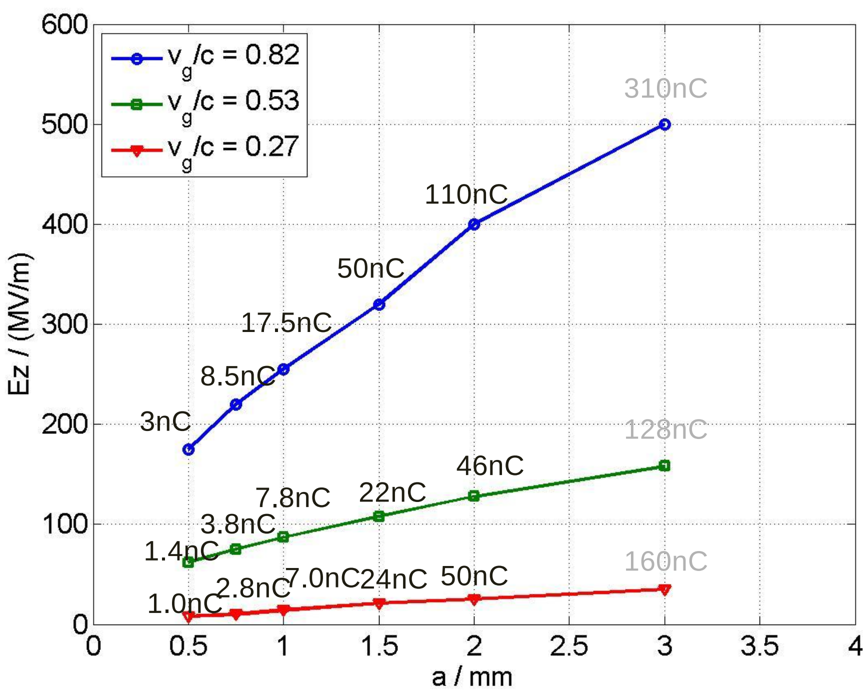
Numerical Cases of a Gaussian Drive bunch w/ BBU Control



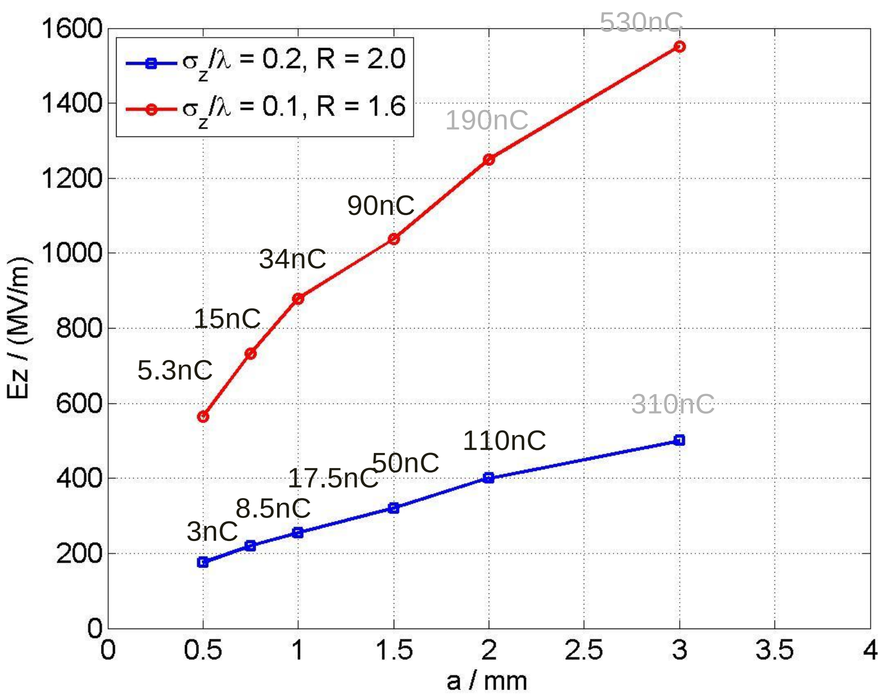
BBU control boundary with optimized quad channel(under as least limits as possible, like practical quad strength, emittance, etc.)

Other parameter's effects

group velocity



bunch length

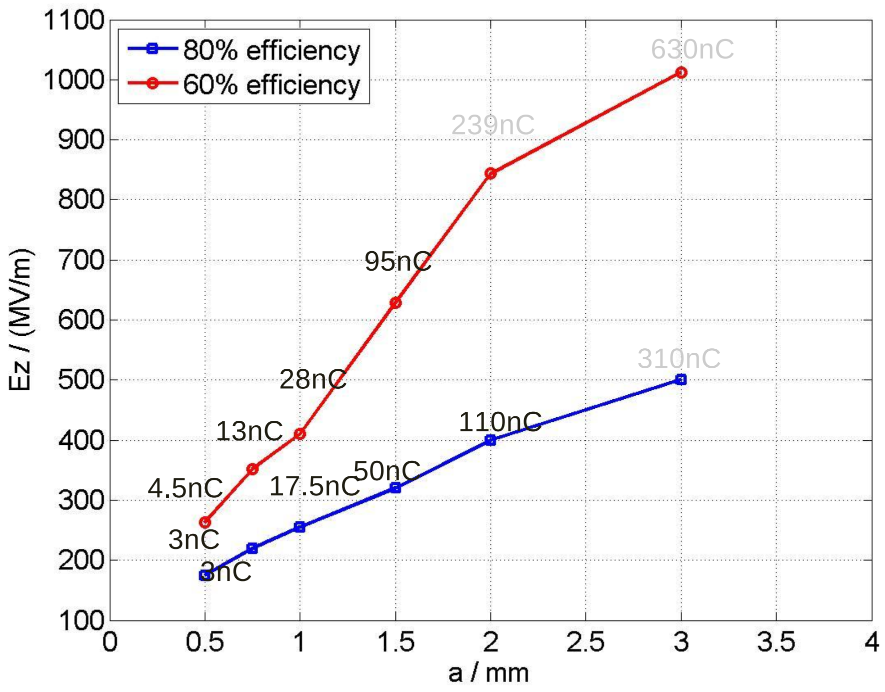


Reason: vg↑ mode separation ↑ dipole modes↓

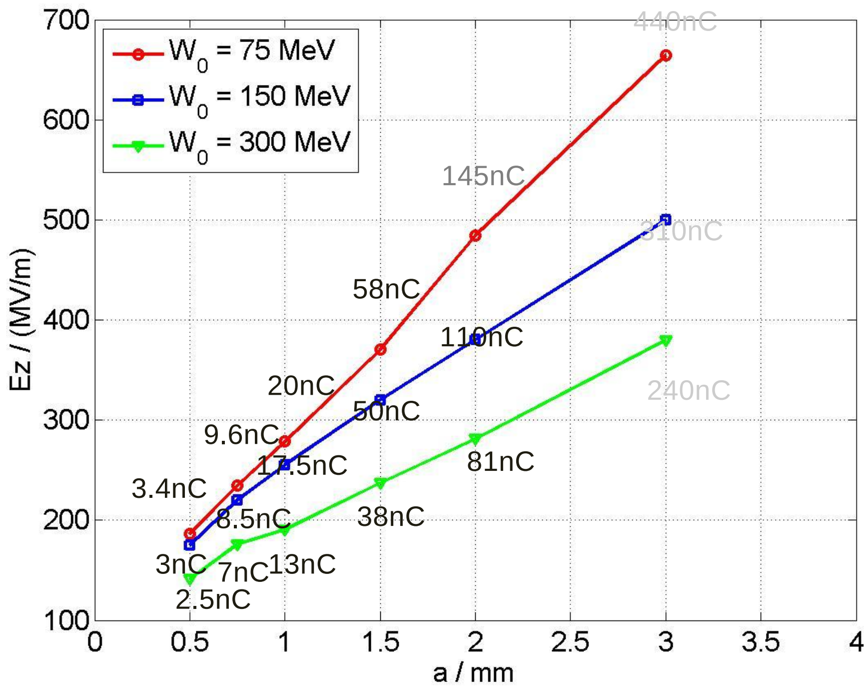
Reason: sigz↓ Ez↑ R↓

Other parameter's effects

efficiency



initial drive energy



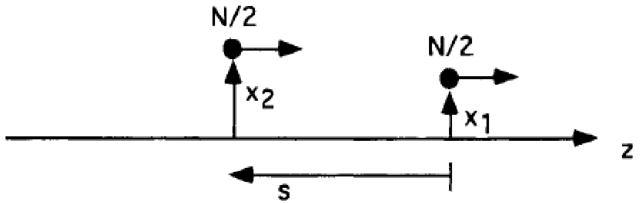
efficiency↓ propagation length↓

W0↑ B′/Bρ↓

Back to Double Triangular Bunch

Wakefields for DT bunch

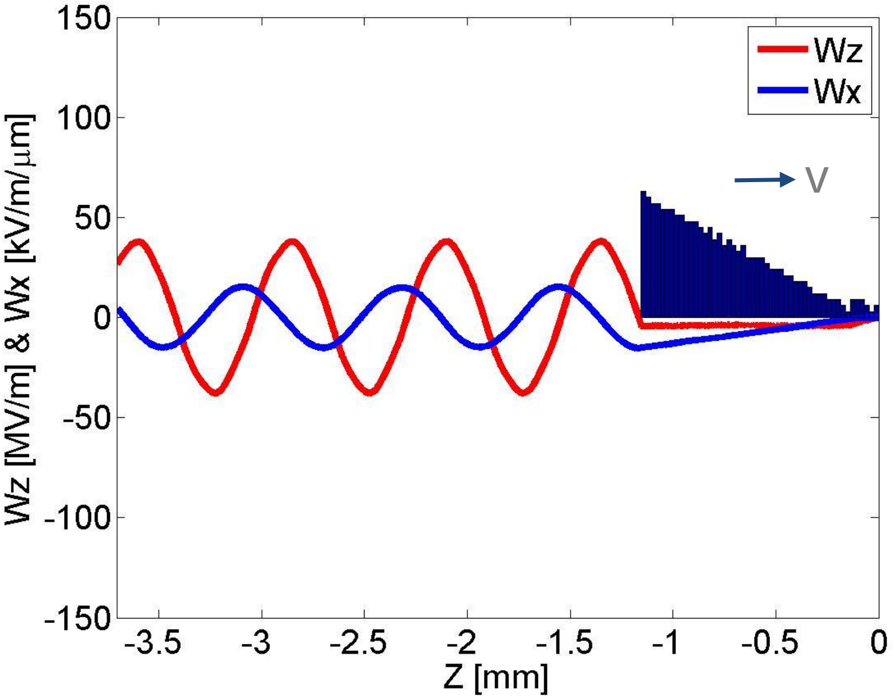
Flat W_z
→ Same energy drop for all the particle



$$\ddot{x}_1 + \omega_1^2 x_1 = 0$$
$$\ddot{x}_2 + \omega_2^2 x_2 = W_x(x_1)$$

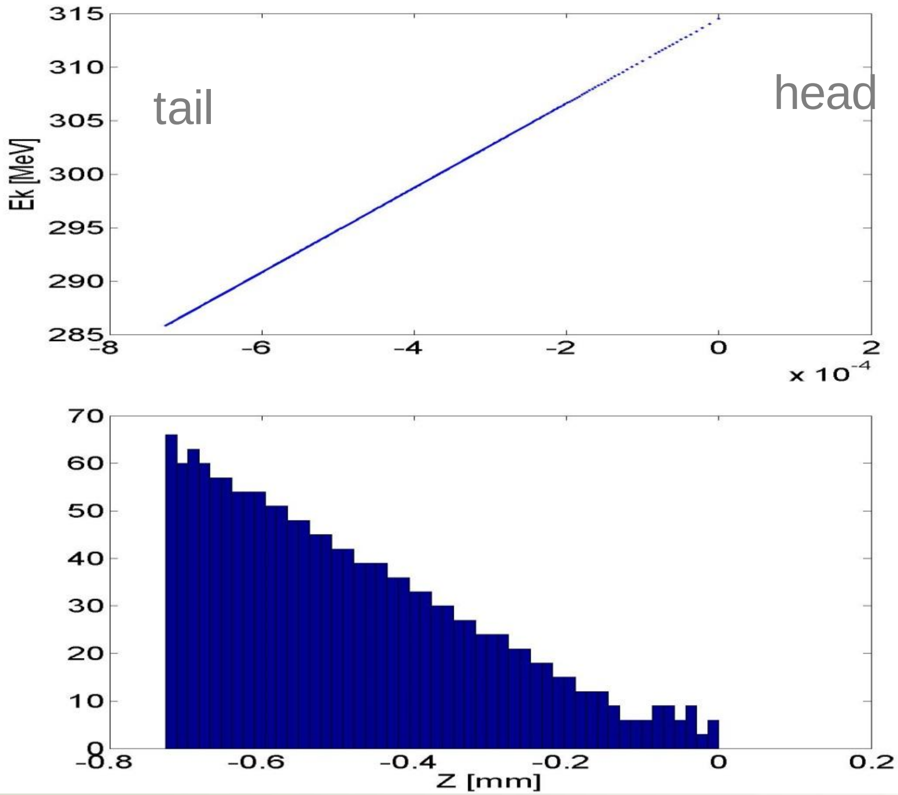
→ ω1 = ω2 in FODO channel
→ Synchronized oscillation
→ x2 grows faster by transverse kick

In order to perform BNS damping to control BBU, it needs an initial energy chirp for DT bunch.



Add initial linear energy chirp to the DT beam

- Define chirp factor $= (W_{head} - W_{tail})/\langle W0 \rangle$
- i.e. chirp factor = 0.1 means W0 = 285 ~ 315 MeV



Improve BBU control by tapering L_q instead of tapering B'

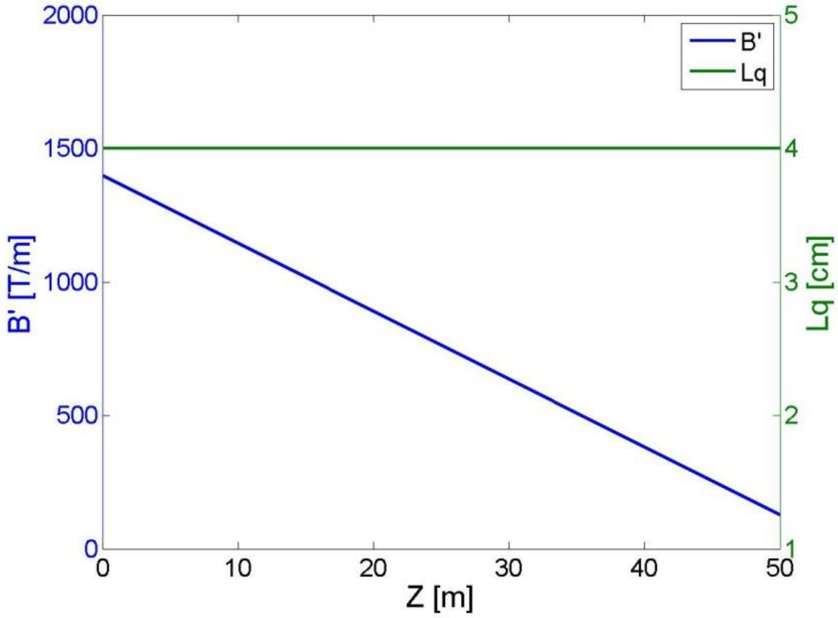
Option 1: Keep L_q and modifying B' as energy drop.

- When beam energy is down to zero, B' approaches 0.

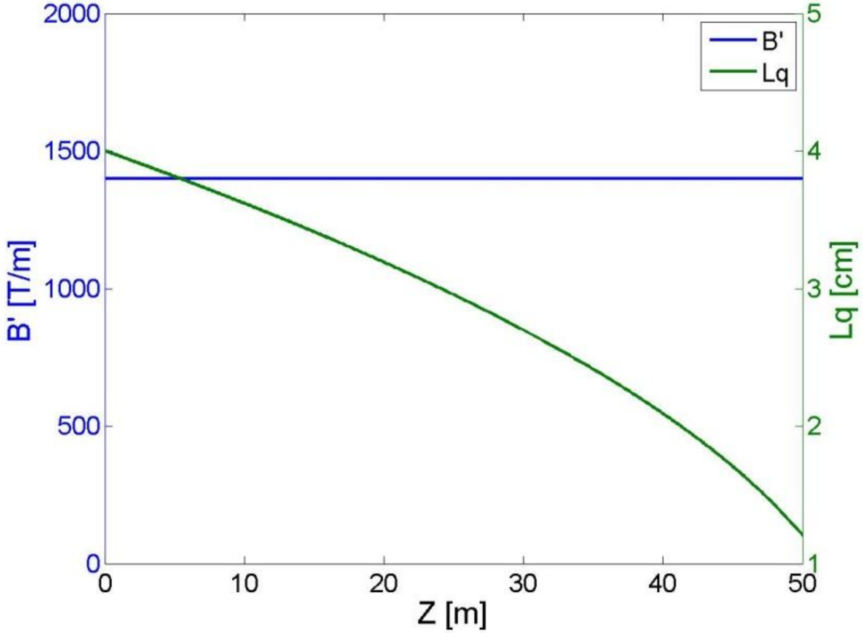
Option 2: New: Keep $B' = 1400T/m$ and modifying L_q.

- Perform stronger focusing than the 1st method.

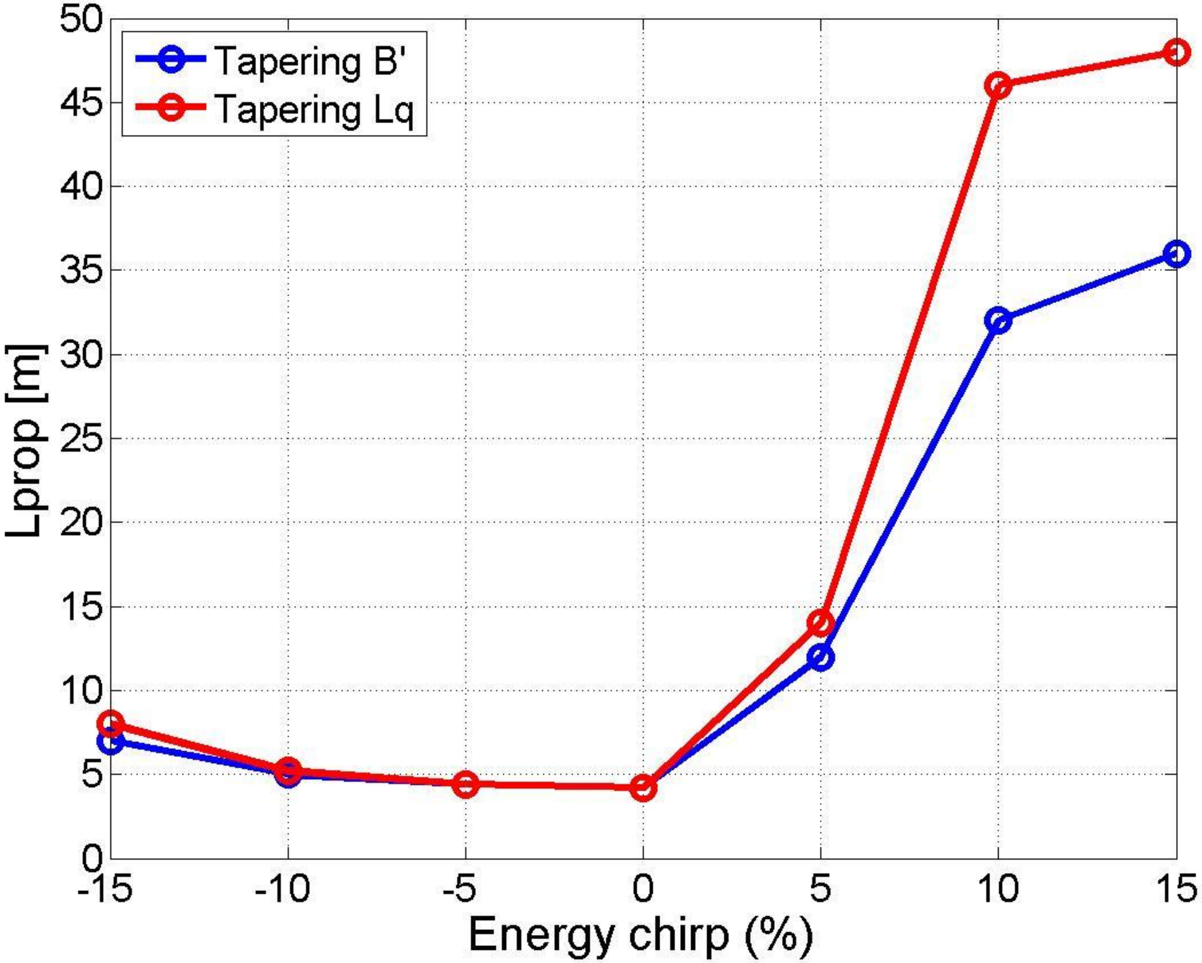
Option 1



Option 2



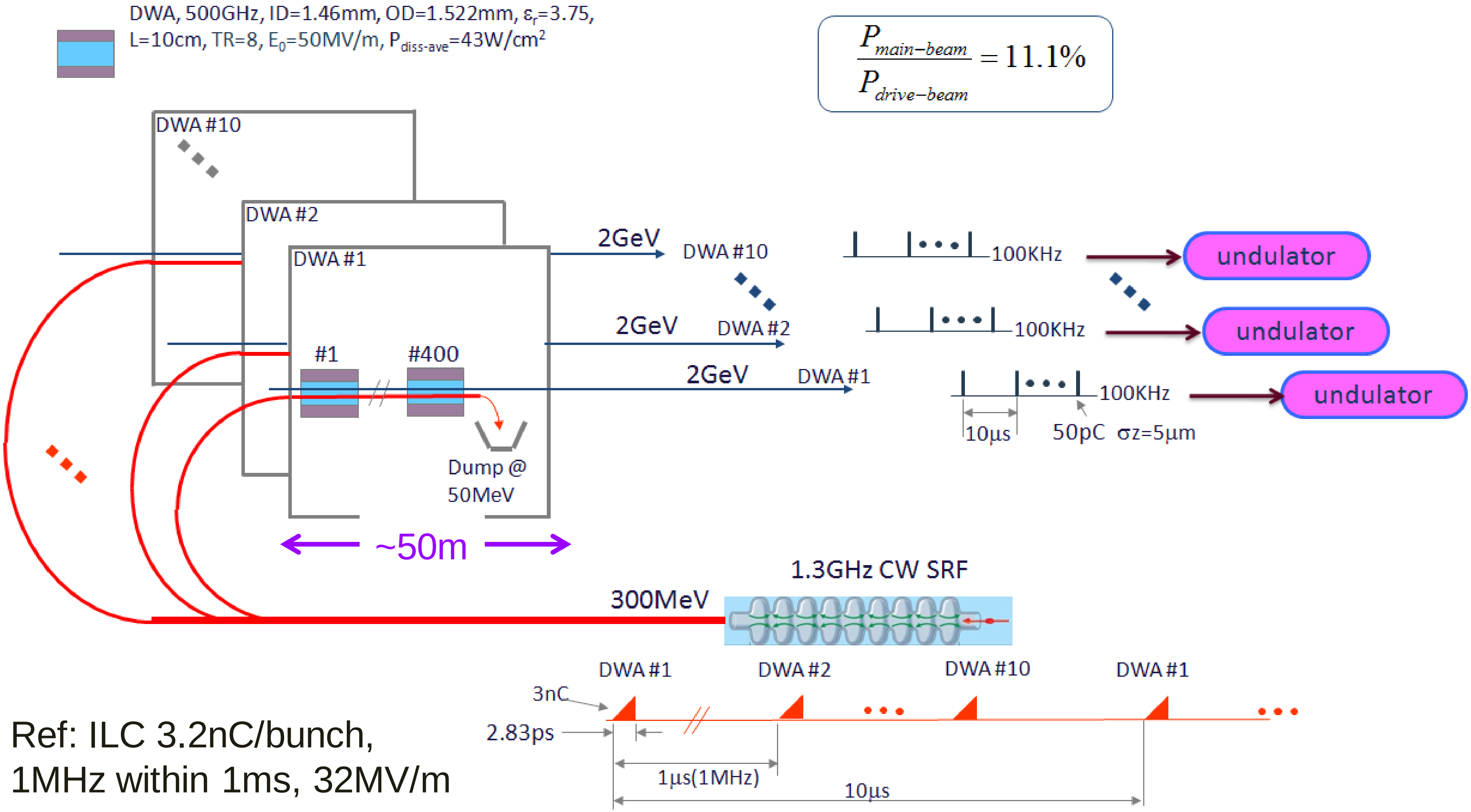
propagation vs energy chirp



For 10% chirp, propagation = 46m with 81% efficiency.

A New Set of Parameters of DWA FEL Scheme

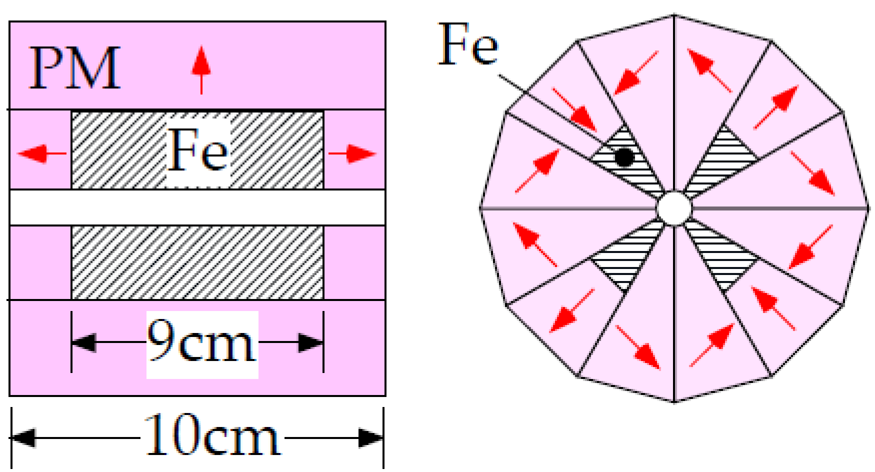
High rep. rate, X-ray FEL user facility based on a 2 GeV DWFA

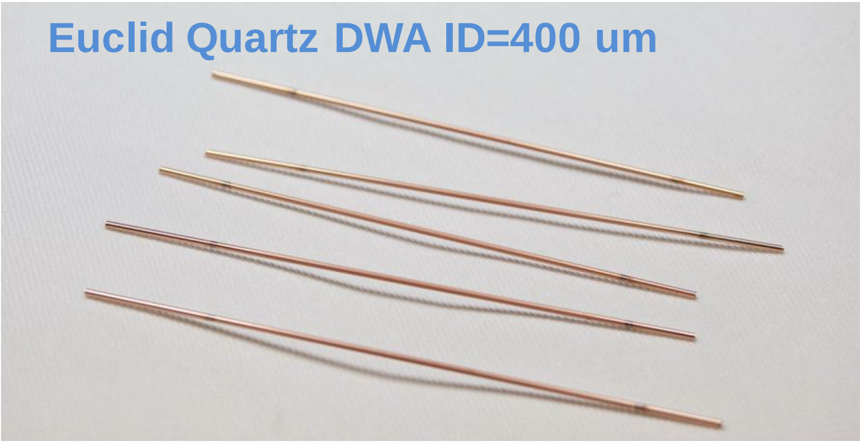


Ref: ILC 3.2nC/bunch,
1MHz within 1ms, 32MV/m

Next Steps

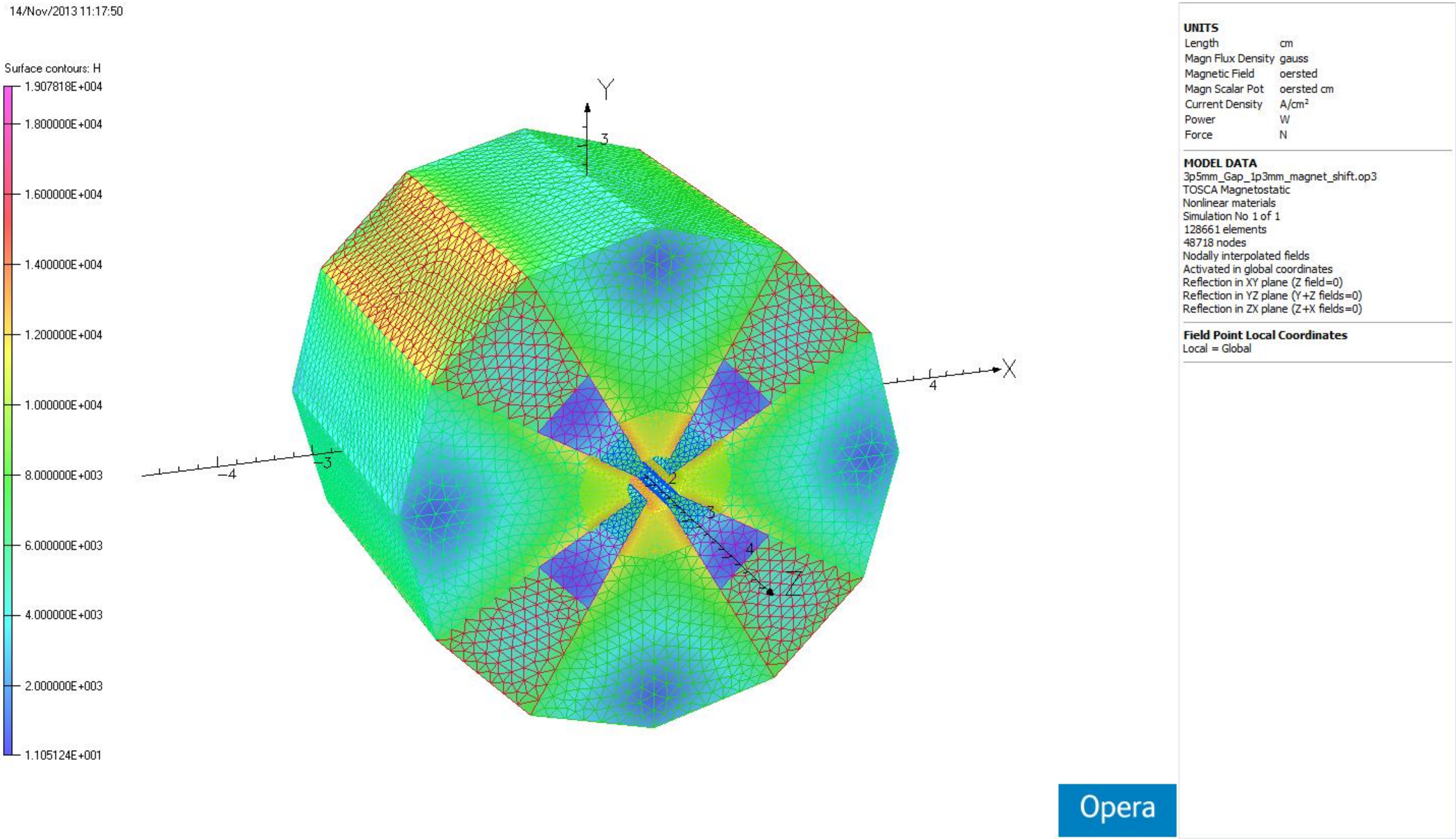
1. Confirmation of BBU study by other well-established simulation code
2. Behavior of witness beam in the same DWA channel
3. Implementation of quads to meet the requirements
4. Design an experiment of beam propagation and control in a meter-scale DWA





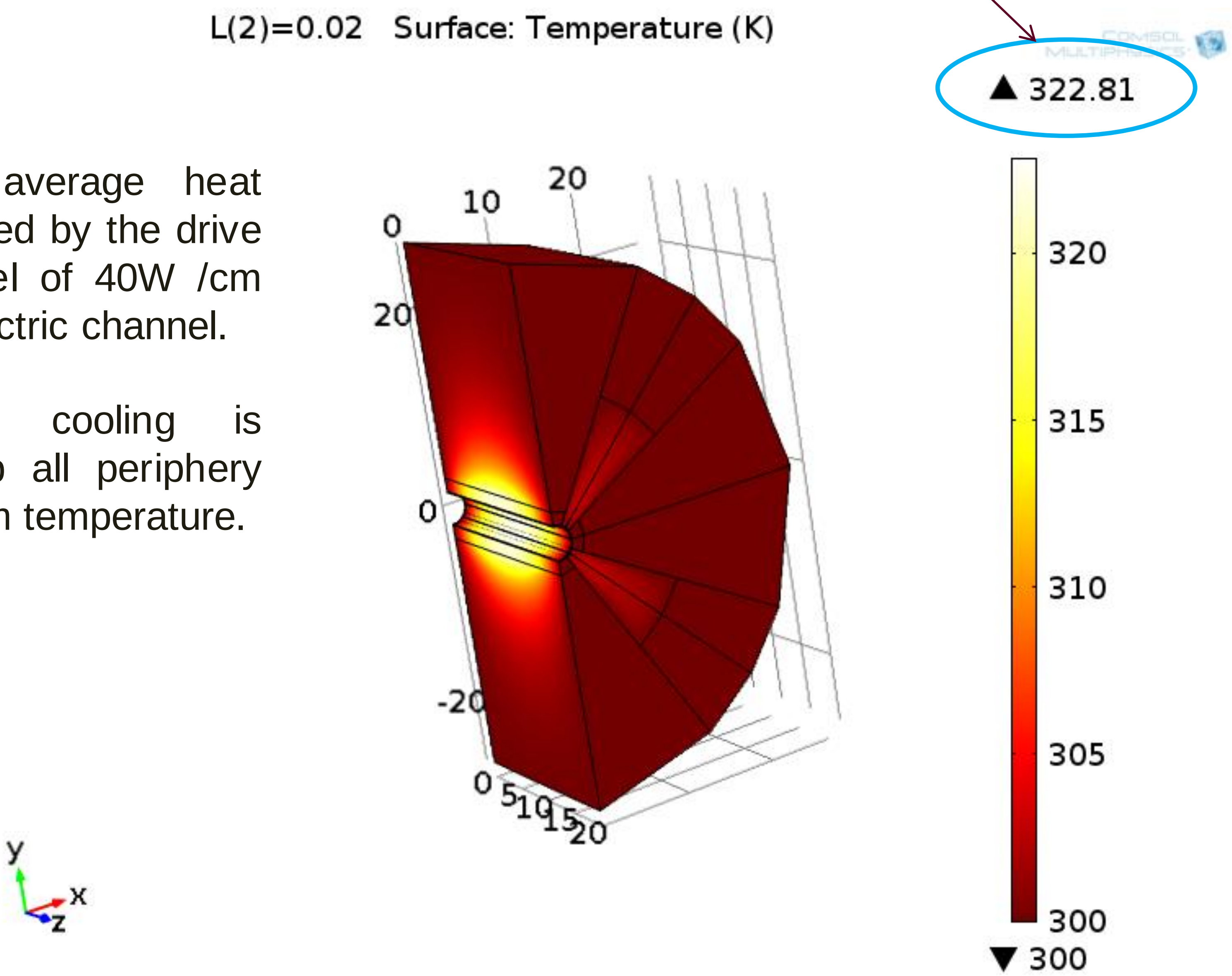
Y. Iwashita, et al, PAC2003

The PMQ designed by Melike Abliz, Isaac Vasserman and Alexander Zholentz of APS with a gradient of 1T/mm and a bore diameter of 3.5 mm.



Temperature variation inside the 2 cm long quad

rather modest temperature rises.



• Assuming an average heat power load induced by the drive beam at the level of 40W /cm length of the dielectric channel.

• Assuming the cooling is provided to keep all periphery surfaces at a room temperature.